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Sustainable transport strategy for promoting zero-emission electric scooters in Taiwan

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ABSTRACT

In Taiwan, the government considers the zero-emission scooters to be a sustainable form of transport like walking, cycling and public transport, which play a vital role to support sustainable urban mobility. Therefore, the development of zero-emission scooters is an important strategy in constructing the sustainable transport network of Taiwan. It is also the government's priorities about the policy of emission-reduction and energy-conservation in the transportation sector. Recently, Taiwan launched a new program for subsidy of purchasing zero-emission scooters, which aimed to shift the petroleum-powered scooters to the electric scooters. The present paper is providing an update review of the promotional programs in developing zero-emission scooters in Taiwan. It introduces the status of the establishment and progress of policy, standards, subsidies to users and manufacturers, practice infrastructure, and technology development. Moreover, the contribution of replacing petrol scooters by zero-emission scooters such as battery-powered electric scooters and fuel cell scooters to reduction in greenhouse gas (GHG) emission and improvement in energy efficiency is evaluated.

Contents

1. Introduction

Urban areas face today the challenge of making transport sustainable in minimizing emissions of carbon dioxide and pollutants [1]. The choices that people make in the way they travel will be essential for the success of the overall strategy to combat climate change. Taiwan is a mild climate island and most people live not far away from their working place. Motorcycles and scooters become a popular form of transport since the riders enjoy the freedom of riding in the open air, and can run errands in their neighborhood with fewer parking hassles. In addition, they benefit from the convenient way of transport since many roads in Taiwan feature separate lanes (Fig. 1) and intersection turn boxes for these two-wheel vehicles. More importantly, scooters generally con-

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Fig. 1. Separate lanes for scooters on the roads of Taiwan.

Fig. 3. View of petrol scooters in a parking lot of Taiwan.

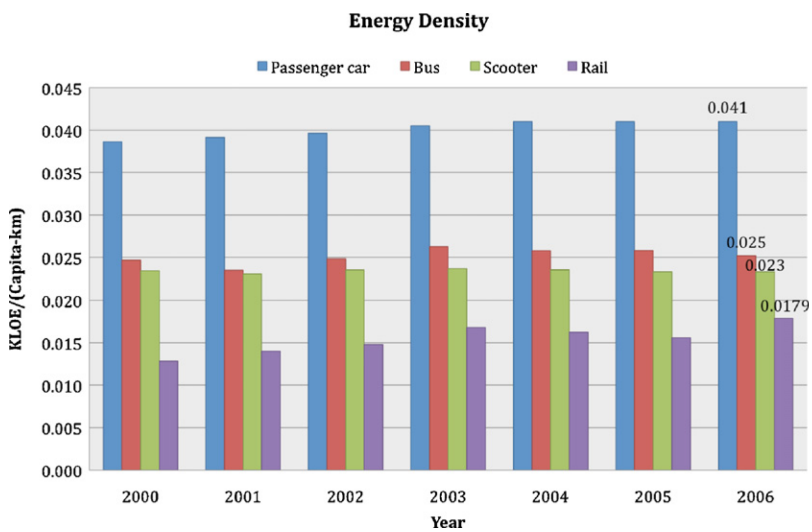

Fig. 2. Comparison of energy density for various petrol-vehicles in Taiwan.

sume less fuel and than passenger cars [2]. According to the statics by Ministry of Communications (MOC) of Taiwan, as shown in Fig. 2, the average energy density (KLOE/km) per capita for the scooter is comparable to that of the public bus, and is only about half of that of the passenger car. Even though, their impact on traffic emissions cannot be overlooked due to dense scooters in streets of Taiwan (Fig. 3). In addition, the emission standards for the petrol scooters (also known as internal combustion engine (ICE) scooters) are less stringent than the petrol passenger cars [3].[1] Therefore, the relevance of overall pollutants and greenhouse gas (GHG) emissions from petrol scooters could not be negligible. The transportation sector accounts for about 14% of the total nationwide GHG emissions in Taiwan each year [4].

In response to the energy and environmental impacts caused by the petrol scooters, Taiwan government has implemented many measures to enhance the energy efficiency and reduce the emission of the petrol scooters. The major strategy is to shift the petrol scooters to the zero-emission scooters. The purpose of the present paper is providing an update review of the promotional policies in developing zero-emission scooters in Taiwan. It introduces the status of establishment and progress of policy, standards, subsidies to users and manufacturers, practice infrastructure, popularization activities, and technology development. Moreover, this study reviewed the previous promotional program of electric scooters powered by lead-acid batteries, assessed the recent measures in promotion of electric scooters lug with lithium-ion batteries, and compared these two programs thereafter. Finally, potential effects of replacing petrol scooters by zero-emission scooters such as battery-powered electric scooters and fuel cell scooters on the reduction in greenhouse gas emission as well as energy consumption are examined.

2. Status of petrol scooter in Taiwan

As shown in Fig. 4, by the end of 2007, scooters in Taiwan amounted to 14 million registered units, composing 67% of all kinds of vehicles. With 23 millions inhabitants and 14 million scooters in the 36 thousand square kilometer area, Taiwan is one of the highest scooter density area in the world. On average, every two people own one scooter and 88% of families have at least one scooter. However, ICE scooters cause serious environmental pollution and emit great GHG. According to the statistical data reported by Environmental Protection Administration (EPA), all scooters emit 0.33 million tons of CO and 90 thousand tons of HC

[1] Emission Standards for petrol passenger car: CO: 2.11 g; HC: 0.045 g/km; NOx: 0.07 g/km; Emission Standards for Patrol scooter: CO: 2.0 g/km; HC: 0.8 g/km; NOx: 0.15 g/km.

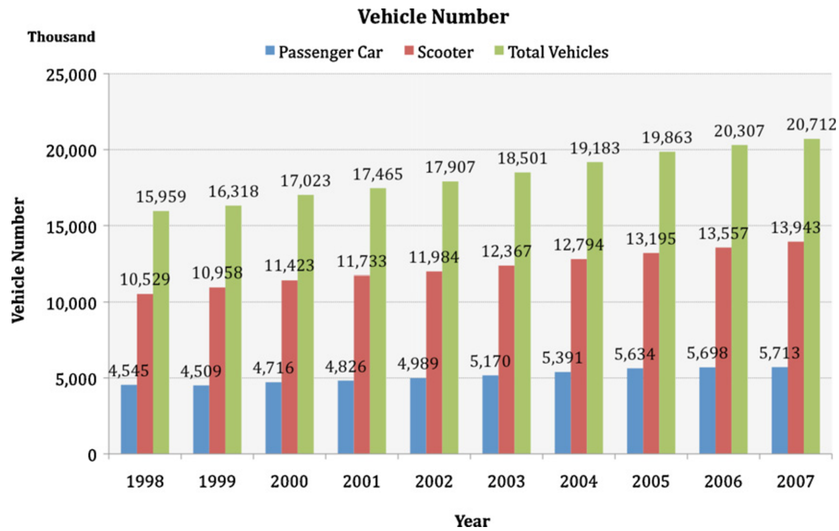

Fig. 4. Development of scooters in the past decade in Taiwan.

Table 1
Summary of scooter emission limits in EU and Taiwan.

Year	Emission limits (g/km)		
	CO	HC	NOX
Europe commission[a]			
Euro 1 from 1999 (EC Directive 97/24)[b]	13.0	8.0	0.1
Euro 2 from 2003 (EC Directive 02/24)	5.5	1.2	0.3
Euro 3 from 2006 (EC Directive 02/24)	2.0	0.8	0.15
Taiwan[a]			
Phase 1 Emission Standards from 1988	8.8	–	5.5
Phase 2 Emission Standards from 1998	4.5	–	3.0
Phase 3 Emission Standards from 2002	3.5	–	2.0
Phase 4 Emission Standards from 2004	7.0	–	1.0
Phase 5 Emission Standards from 2007	2.0	0.8	0.15

[a] Engine size <150cc.
[b] Four-stroke engine.

every year, making up 12% and 8% of the total pollutants. In addition, ICE scooters emit over 2 million tons of CO_2 each year in Taiwan.

In order to alleviate the air pollution and in response to the introduction of standards in overseas markets, such as Japan and the European Union, Taiwan has launched the so-called Phase 5 Emission Standard recently, which is comparable with the Euro 3 emission standards. As shown in Table 1, Euro established its first emission standards Euro 1 (EU Directive 97/24/EC) for ICE scooter in 1999. In 2002, EU ministers took additional steps to agree a new set of emission limits under a proposed new directive (2002/24). This directive raised the existing standards in two stages, one which came into effect in 2003 requiring better engine efficiency and exhaust treatment, and the other coming into effect in 2006 to bring scooter emissions up to the current Euro Standards that apply to new scooters. In Taiwan, the emission standards for scooters were setting since 1988. After several revising processes, Phase 5 emission standards noticed on 2006, formally implemented on 2007, and after 2009, all locomotive products could only be produced in accordance with these regulations. It is noted that the current EU and Taiwan emission standards are the most stringent emission standards in the world. The scooter emissions from engine size below 150cc should be limited to 2.0 g/km, 0.8 g/km, 0.15 g/km for carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOX), respectively.

Strictly speaking, raising the emission standards of the petrol scooters is a temporal measure for transition to zero-emission scooters. The development of zero-emission scooters is the ultimate goal in constructing the sustainable transport network in Taiwan.

3. Progress of electric vehicles in Taiwan

3.1. Light-duty electric vehicle program in 1970s

Table 2 summarized the major promotional programs of electric vehicles in Taiwan since 1970s. When the oil crisis hit the world in the early 1970s, Taiwan launched its first electric vehicle program, which aimed to develop light-duty electric vehicles as alternatives of petroleum-powered vehicles. Lead-acid batteries powered the electric vehicles. In the program, National Tsing-Hua University (Taiwan), Tanyon Iron works, and Yuasa Battery Company worked together to produce a fleet about 200 vehicles, which were mainly used for the mail-delivery service. It continued for about 10 years until the energy crisis subsided.

Table 2
Promotional programs for of electric vehicles in Taiwan.

Phase	First phase	Second phase	Third phase
Program	Development of light-duty electric vehicle	Action plan for developing electric scooters	Program for purchase subsidies and incentives offered for E-scooters
Period	1973–1983	1998–2003	2009–2012
Authorities	NSC	EPA	IDB
Vehicle type	Light-duty vehicle	Scooter	Scooter
Battery type	Lead-acid battery	Lead-acid battery/Ni–H battery	Li-ion battery
Subsidized amount	NA[a]	NTD 16,000–33,000 per unit[b]	NTD 6500–11,000 per unit
Subsidy cap (unit)	NA[a]	26,000	160,000

[a] It was in the stage of research, development, and demonstration. The subsidy program was not available in the program.
[b] Average subsidy was NTD 25,000/unit.

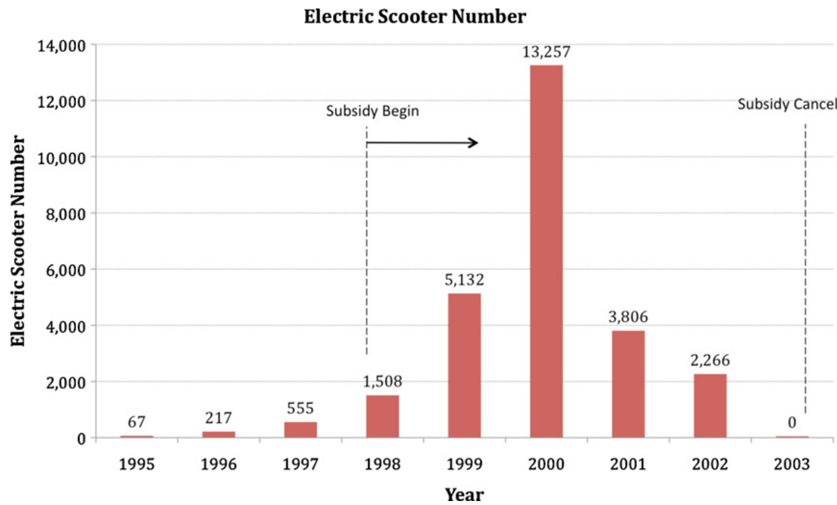

Fig. 5. Distribution of registered electric scooters between 1998 and 2003 in Taiwan.

3.2. Electric scooter incentive program in 1998–2003

In response to renewed worldwide interest in electric vehicles in 1990s, which was motivated mainly by air pollution concerns, Taiwan started its second phase of clean-vehicle program about a decade ago. In light of the high density of scooter distribution as well as the robust indigenous scooter industry, Taiwan government considered it would be more realistic in developing electric scooters rather than electric passenger cars. Therefore, Environment Protection Administration (EPA) adopted a subsidy program of "Action Plan for Developing Electric Scooters" to subsidize the purchase of electric scooters since 1998 in response to the government's new priorities of promoting electric vehicles. It was one of the first subsidy plans in the world to introduce the 2-wheel electric scooter mandate to replace 50cc petrol scooter. In this incentive program, as shown in Table 2, each electric scooter got an average subsidy of NTD 25,000 (USD 800, around USD 1500 per vehicle). However, inconsistent quality and inadequate maintenance of these electric scooters dampened the enthusiasm of customers quickly. As shown in Fig. 5, the annual domestic purchase of electric scooters reached a peak over 13,000 in 2000 and rapidly dropped to less than 3000 in 2002. The government therefore canceled the subsidy program in 2003 because the number of electric scooters could not reduce air pollution in any significant way. In the program, a total of 26,000 units were sold by 2003 and the government spent about NTD 1.8 billion (USD 55 million). That is each registered unit cost the taxpayer NTD 70,000 on average, which is far more than the purchase price of the electric scooter.

3.3. Electric scooter incentive program since 2009

Recently, electric vehicles have receives a great attention worldwide again since they have much lower CO_2 emissions than gasoline-fueled ones and thus can make a big contribution to reduction in CO_2 emissions in the transportation sector. Taiwan government therefore started its third phase of promotional program of electric vehicle in order to reduce the GHG emission, which proposed a new incentive program to subsidize the purchase of electric scooters. It is also a part of the national policy in energy-conservation and emissions-reduction [5]. Before implementing the new program, a detailed user survey was made by the Industrial Development Bureau (IDB) of Ministry of Economic Affairs (MOEA) to avoid the possible failure as happened in 1998 [6]. After carefully reviewing the key failure factors of the previous promotional program, a comparison of customer requisite (target) and the technical specification of the electrical scooter was made in Fig. 6. In general, the characteristics of powertrain of the scooter such as maximum speed, acceleration, and climbing are

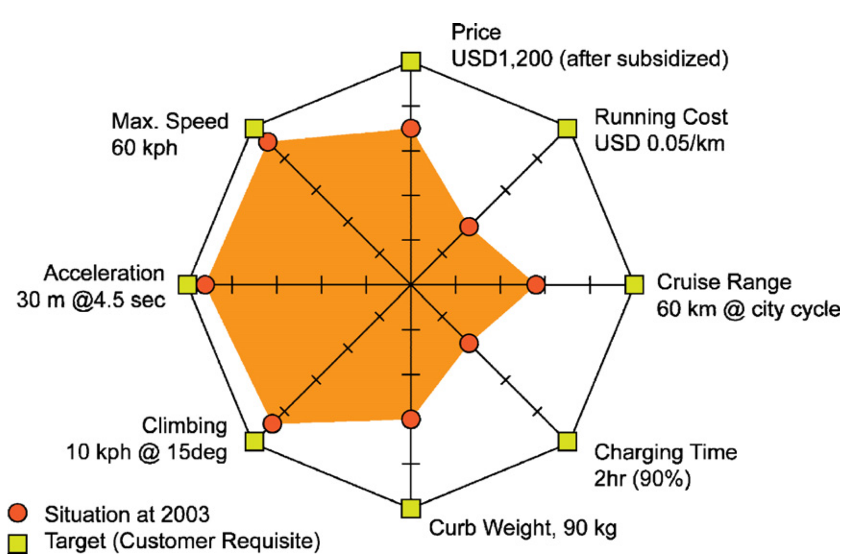

Fig. 6. Consumer requisite (target) and the current engineering specifications of the electric scooters.

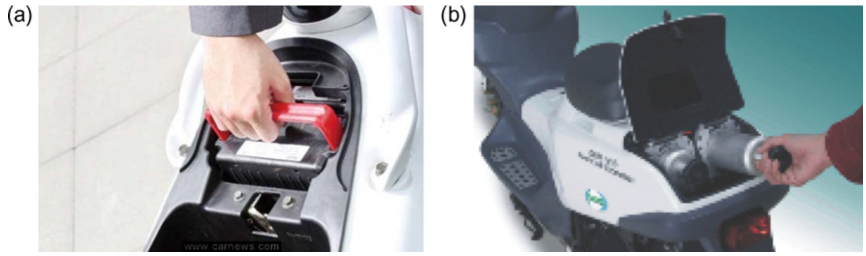

Fig. 7. Exchange system of the energy storage for zero-emission scooters: (a) detachable Li-ion battery pack for electric scooters, and (b) exchangeable metal hydride canister for fuel cell scooters.

acceptable. However, the vehicle cost and the battery performance are much concerned. The majority of the no-go reasons of the previous promotional program were therefore concluded as below:

(1) *Inadequate cruise range and long charging time:* The consumer requisite of reliable cruise range for most users should be longer than 40 km. However, each recharge of the lead-acid battery taking six to eight hours only last a maximum 20 km.
(2) *Poor durability of battery and high running cost:* The recharge number of the VRLA battery is no more than 200 times during its lifetime, which provides about 4000 km in driving range. The average cost of the battery is higher than NTD 1.65/km, which is far above fuel cost of the petrol scooter.
(3) *Lacking of a nationwide recharging system:* Insufficient infrastructure was one of the major failure reasons of the program. Without sufficient number of recharging stations set up, the riders usually cease the electric scooter embarrassedly on the roads due to the empty of battery.

According to the suggestion by IDB, the difficulties encountered in the previous program (1998–2003) could be lessened by the advanced battery technology and the smart infrastructure. It is believed that the Li-ion battery performs better than the valve-regulated lead-acid (VRLA) battery in the cruse range due its high electricity capacity. In addition, the exchange systems using the portable battery pack designs (Fig. 7(a)) might eliminate waiting for battery charging. Therefore, the new incentive program subsidies the purchase of electric scooters lug with a plug-in detachable Li-ion battery pack instead of the fixed VRLA batteries. The subsidy program begins in November 2009. As shown in Table 3, the subsidy ranges from NTD 6500 to 11,000 per scooter depending on the size of scooter engines. Additionally, the government provides domestic electric scooter makers with subsidies of up to NTD 16 million (USD 753,000), provided that they sell more than 8000 units in the first year of the scheme, 14,000 units in 2010 and 16,000 units in 2011–2012. Moreover, incentives will be provided for the installation of battery-charging facilities, with operators receiving up to NTD 100,000 (USD 3000) per station.

According to the new program, the government expects to subsidize 20,000 scooters by 2010, rising to 160,000 scooters by 2012. However, the goal to raise the number of electric scooters in the new plan still faces some challenges, especially battery prices and safety. Based on the cost of the Li-ion battery now, it is very difficult to meet the price targets of NTD 40,000 (USD 1200, after subsidized) for the electric scooter comparable to the 50cc petrol scooter (normal type shown in Table 3). This is the reason why another model classified as a mini type scooter is developed by employing less capacity of Li-ion battery to the smaller scooter. As shown in Table 3, the mini-type electric scooter was equipped with a smaller motor that reduces the top speed to 30 kilometer per hour (kph) and the cruise range to 30 km. It would meet the price target of NTD 40,000 based on the estimation of IDB. As far as safety concern, the state-of-arts Li-ion battery technologies are not mature enough for high-current applications such as electric

Table 3
Subsidy program for electric scooters and their specifications in 2009.

	Year of purchase	Normal type	Mini type
Subsidies for buyers	2009–2010	NTD 11,000	NTD 8000
	2011	NTD 10,000	NTD 7200
	2012	NTD 9000	NTD 6500
Specifications	Grade ability	>20 kph @ 18%	>10 kph @ 18%
	Maximum speed	>50 kph	>30 kph
	Acceleration	<10 s @ 0–100 m	<8.5 s @ 0–50 m
	Cruise range	>40 km @ ECE47	>30 km @ ECE47
	Battery durability	>85% of initial range after 5000 km durability	>85% of initial range after 3000 km durability
	State-of-charge	>2 km for warming @ initial and after durability or >85% accuracy @ initial and after durability	
	Photo		

Note: Once the annual subsidy budget has been used up, the subsidies will be stopped temporarily. Qualified purchases for which subsidies are not paid within the year of purchase, however, will be given priority for payment the following year.

vehicles, especially for the scenario of the extractable charging at home outlet. In addition, potential riders are reluctant to lug heavy (about 5–10 kg) batteries home for recharge (Fig. 7(a)). Such approach is expected to fail as happened years ago if the abovementioned obstacles cannot be overcome. Nevertheless, the government optimistically estimated that the scheme would cut GHG emissions while helping Taiwan to establish a position in the global electric scooter industry.

4. Development of fuel cell scooters in Taiwan

4.1. Technology development of fuel cell scooters

In 2000, the Sixth National Science and Technology Conference urged the government to set up guidelines and a roadmap for fuel cell development in Taiwan. The strategy was to promote effective cooperation among domestic industries to develop practical systems and peripheral components for getting a competitive position in the worldwide fuel cell industry. In 2001, the annual meeting of Science and Technology Advisory Group (STAG) of the Executive Yuan further recommended to establish promotional groups to put forward the fuel cell related products such as electric scooters, distributive power generators, and portable power for 3C application.

Among various fuel cell applications, fuel cell vehicles are regarded as the potential largest market in the world [7–10]. The majority of automakers such as GM, Toyota, Nissan, Ford, and Daimler-Chrysler devoted greatly into developing fuel cell passenger cars either independently or in collaboration with other companies. In general, fuel cell passenger cars equipped with an engine higher than 30 kW [11]. As far as the indigenous technology and limited resource concerns, Taiwan should not duplicate activities in developing the abovementioned fuel cell passenger cars. In contrast, it is highly important to strategically decide the niche products in the development of fuel cell industry in Taiwan. Actually, Taiwan has the opportunity of leading the world in small-vehicle technology (<10 kW) such as fuel cell scooters and wheelchairs that would be the domestic niche industry. In addition, in the Taiwan's sustainable transport strategy, the fuel cell scooter plays an important role since it is regarded as the approach next to the Li-ion battery electric scooter.

In 2001, Taiwan government awarded a domestic fuel cell manufacture, Asia Pacific Fuel Cell Technologies, Ltd. (APFCT), an R&D grant for "Preliminary Study in the Application of Fuel Cell Technologies to Scooters," which was successfully completed in January 2002. During this period, three prototypes of fuel cell scooters ZES II, ZES II.5 and ZES II.6 were carried out. As a specific accomplishment of this study grant, ZES II.6 was the world's first publicly known fuel cell scooter tested and certified by a government established testing laboratory. In August 2002, IDB granted another project of "Development of Proton Exchange Membrane Fuel Cell Stack Applications under the program of "Leading Product Development Project". This important grant exemplified the Taiwan government's interest and support of fuel cell technologies. This project completed the design of the fuel cell system and demonstrated the world's first automated fuel cell volume production system in 2004. This automation production system is a milestone in the advancement of fuel cell technology and in its progress towards commercialization.

4.2. Learning demonstration of fuel cell scooters

Recently, the program of learning demonstration of fuel cell scooters and hydrogen infrastructure is undergoing under the "National Research Project on Energy" in Taiwan. The demonstration program involves domestic fuel cell scooters, on-board hydrogen fuel storage, and hydrogen infrastructure model. It tests, demonstrates, and validates complete system solutions of fuel cell scooters in parallel with hydrogen infrastructure, which facilitates an industry commercialization decision by policy makers.

To avoid pitfalls of past failures in promoting recharged-battery driven scooters and liquefied petroleum taxis, hydrogen infrastructure should be carefully considered in the development of fuel cell scooters. Fig. 8 shows the hydrogen infrastructure for fuel cell scooters. The metal-hydride canister is employed in the fuel cell scooters in considering storage density, convenience, safety and cost. As shown in Fig. 7(b), the canisters are designed with quick engagement/disengagement connectors for easy replacements. Rather than refilling hydrogen into an empty hydrogen tank, the scooter drivers exchange empty metal-hydride canisters with filled ones in the gas stations or convenient stores and thus do not need to be in direct contact with hydrogen. Logistics companies then circulate the empty metal-hydride canisters. This means the empty metal-hydride canisters can be delivered to and replaced at the exchange stations, which in turn the empty metal-hydride canisters are delivered back to the hydrogen factory. The learning demonstration program will take the central management of fuel

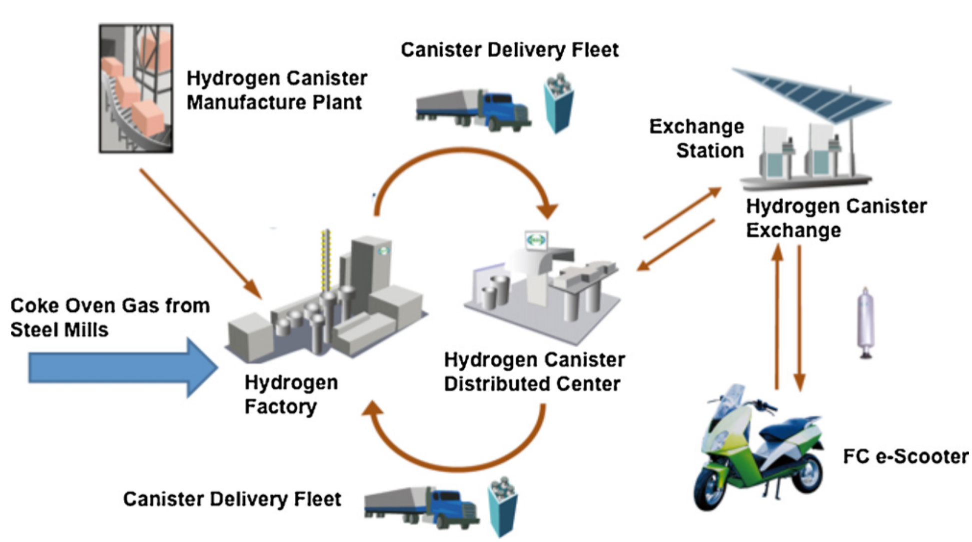

Fig. 8. Infrastructures of fuel cell scooters.

cell scooters such as the fleet usage in newspaper, mail and milk delivery, because this will be easier to implement the fleet management process to secure the safety of the hydrogen and fuel cells. Another important feature of the demonstration program is to help identify those codes and standards that will be necessary and useful for the commercialization of fuel cell scooters, facilitate the development of those codes and standards and support publicly available research that will be necessary to develop a scientific and technical basis for such codes and standards. This project could signify a new milestone in the commercialization of fuel cell scooters in Taiwan.

5. Perspectives of fuel economy and GHG emission

In addition to improvement of local air quality, the zero-emission scooters would have the concrete benefits of reducing GHG emission and enhancing the energy efficiency in the transportation sector. In the present study, the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model developed by Argonne National Laboratory was used to examine the life-cycle (or well-to-wheels, WTW) energy and emission effects of scooter and fuel technologies. The GREET model has been applied to provide well-to-tank (WTT) results for various fuels for vehicles [12–15]. In particular, it has been used to examine the energy and emission effects of different fuel production pathways. For this study, the model was modified to conduct WTT analysis of petrol, electricity, and hydrogen for various scooters.

5.1. Fuel pathway

Fig. 9 shows a comparison of the fuel pathways/scooters chosen in the present work. The fuel pathways include petroleum-to-gasoline, fuel mix-to-electricity, natural gas (NG)-to-hydrogen and coke oven gas (COG)-to-hydrogen. In the gasoline-powered scooters, energy efficiencies of petroleum refinery can be used to determine the total amount of energy use for fuel operation. With the data given by China Petroleum Cooperation (CPC), the GREET model estimated about 87.7% in energy efficiencies of producing gasoline from petroleum. As for the electric scooters, they emit gases indirectly since they use widely available power from fossil-fuel power plants, which burn coal, natural gas and oil, and release greenhouse gases including carbon dioxide. Therefore, a key factor in determining the energy-conservation and emission-reduction of electric scooters is the source of the electricity that is

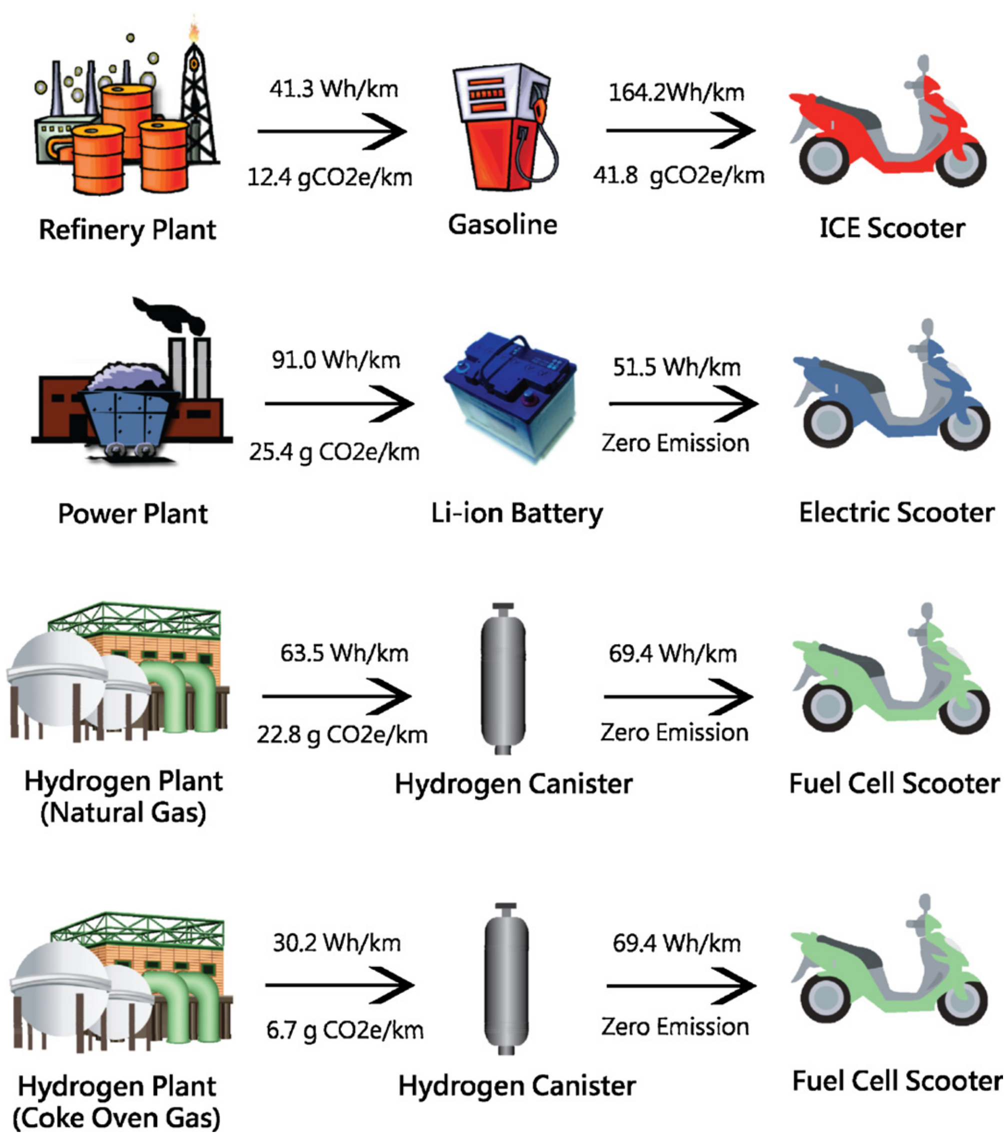

Fig. 9. Illustrations of fuel pathway among four kinds of scooters.

Table 4
Mix of sources for average electric generation of Taiwan in 2008.

Sources	Amount (GWh)	Share (%)
Coal	123,969.2	52.02
Oil	13,367.2	5.61
Nature gas	48,364.2	20.29
Nuclear power	40,826.9	17.13
Hydropower[a]	7,772.3	3.26
Wind power	589.3	0.25
Other	3437.0	1.44
Total	238,325.9	100

[a] Conventional and pumped storage hydro included.

Table 5
Typical composition of coke oven gas.

Contents	Share
Hydrogen, H_2	57.4%
Methane, CH_4	24.6%
Carbon monoxide, CO	7.1%
Carbon dioxide, CO_2	2.4%
Nitrogen, N_2	6.1%
Oxygen, O_2	0.1%
Other hydrocarbons (ethane, propane, etc.)	2.4%

Source: China Steel Corporation (CSC).

used to charge the battery. Table 4 shows the average generation mix of Taiwan in 2008 [4], which is used to calculate the carbon intensity (gCO_2e/kWh) of the electricity for charging the battery. The hydrogen for fuel cell scooters is produced from either NG or COG. At present, methods to produce hydrogen from natural gas steam methane reforming (SMR) are well developed. It accounts for over 95% of all hydrogen produced in Taiwan. The SMR process consists of the reformation of natural gas and the shift reaction. The first step of the SMR process involves methane reacting with steam to produce a synthesis gas, a mixture primarily made up of H_2 and CO. In the second step, known as a water gas shift (WGS) reaction, the carbon monoxide produced in the first reaction is reacted with steam over a catalyst to form hydrogen and carbon dioxide. As shown in Fig. 8, the empty metal-hydride canisters are fueled with hydrogen in the hydrogen plants, and then transport them from the plants to exchange stations for fuel cell scooter applications. The COG-to-H_2 pathway is simpler than that of NG-to-H_2, which involves H_2 separation from the COG and H_2 compression into metal hydride canister. Table 5 shows that typical COG contains up to 57% hydrogen by volume. By using a process engineering analysis, the energy efficiency for separating the hydrogen by means of the PSA system is estimated about 92%. The PSA system would be driven by electric power purchased from the electric grid. The remainder of the COG-after hydrogen separation-would be used as a process fuel in steel mills.

For the WTW analysis, the fuel economy (tank-to-wheels, TTW) in scooter operation is needed. Table 6 presents the fuel economies for three types of scooters. Of the three, the ICE engine is the

Table 6
Fuel economies of three types of scooters.

Scooter power	ICE engine (4-Stroke 50cc)	Fuel cell	Li-ion Battery
Gasoline consumption (l/km)	0.0184[a]	–	–
Hydrogen consumption ($g H_2/km$)	–	1.5	–
Equilibrium power consumption (Wh/km)	167	50[b]	30

[a] Standard for Vehicle Energy Consumption and Inspection Method.
[b] Road test for ZES IV (APFCT).

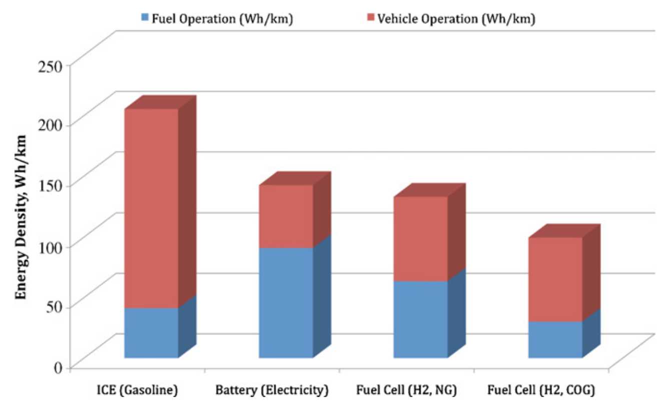

Fig. 10. Comparison of energy efficiency among various scooters.

reference technology to which the Li-ion battery and hydrogen fuel cell are compared.

5.2. Well to wheels results

Figs. 10 and 11 compare WTW results among four kinds of scooters examined in this study. The ICE scooter is the baseline case, which is powered by petrol-based fuels. The second is an electric scooter powered by Li-ion battery that is charged through the generation mix shown in Table 4. The remainder two are fuel cell scooters, which are fueled with hydrogen that is produced from COG and NG, respectively. The hydrogen fueled in the fuel cell scooter is gaseous hydrogen, which is transported metal hydride canister from plants to exchange stations (Fig. 7).

Fig. 10 presents the results of energy density (Wh/km) for the four systems. It is seen from this figure that the zero-emission scooters (including Li-ion battery and fuel cell) reduce total energy use as a result of their fuel economy gains. Battery-powered electric scooters reduce total energy use because of the reductions in energy use during scooter operation (tank-to-wheels stage). Both fuel cell options powered by hydrogen achieve energy reduction benefits. The COG-based options involve H_2 separation only, thus have additional energy reductions.

Fig. 11 shows a comparison of the GHG emission among various scooters. To put the data on the same basis, the vertical coordinate of the figure is presented with per-kilometer GHG emissions. GHG emissions in the present study are CO_2-equivalent emissions of CO_2, CH_4, and N_2O. Although the battery-powered electric scooters are zero emission in scooter operation (TTW emission), the fuel process of electricity however contributes the most GHG emission among the four fuel pathways. Therefore, to capitalize on the full benefits of battery-powered electric scooter, policy makers in

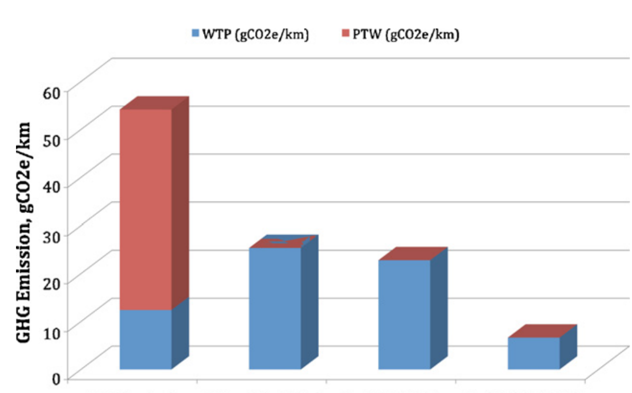

Fig. 11. Comparison of GHG emissions among various scooters.

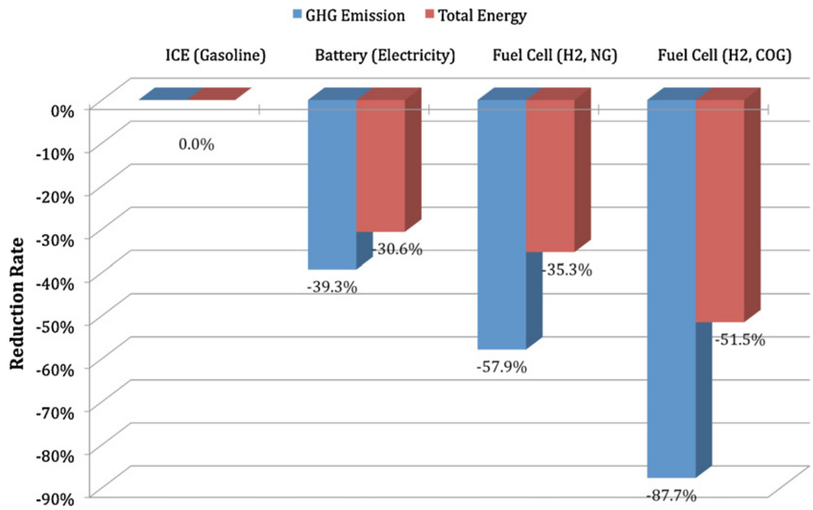

Fig. 12. Reduction rate of GHG emission from the ICE scooters.

Taiwan should consider measures to lower the carbon intensity of the grid. This is also the reason why that the effect of vehicle electrification on carbon emissions is quite dubious [16,17]. Taiwan's grid is currently carbon intensity is about 0.637 kg CO_2e/kWh, which is much higher than those of Japan and France due to high coal use [18], making little carbon benefits of electric scooter over gasoline scooters. As Taiwan's grid decarbonizes from increasing generation from renewable energy and/or nuclear power, electric scooters can really provide a pathway toward low-carbon personal transportation. Actually, the recently passed "Statute for Renewable Energy Development" [19] that increases the non-carbon electricity is examples of policies that will help achieve that goal.

While fuel cell scooter fueled by hydrogen produced with NG SMR achieve moderate GHG emission reductions, the other hydrogen fuel cell scooter option achieves larger reductions. The large reductions by COG-based H_2 fuel cell scooter under are attributable to the fact that most of the carbon in coal is converted into carbon in coke during the coking process in steel mills. In addition, COG-to-H_2 production involves only separation of hydrogen from COG. This separation process itself does not generate CO_2 emissions, while the electricity used for the PSA unit bears emissions in electric power plants. The GHG emissions under the COG-to-H_2 are low because only H_2 separation is involved and because COG is a by-product of coking units [20].

Fig. 12 shows the contribution of reduction in GHG emission and total energy usage for various scooter/fuel systems. All of the three alternative scooter/fuel systems have the advantage in both GHG emission reduction and energy conservation. The COG-based H_2 fuel cell scooters have the best performance with the reduction of GHG emission up to 88% and the improvement of the energy efficiency up to 52%.

6. Conclusion

Zero-emission scooters are regarded as a sustainable form of transport in Taiwan. The government launched its first promotional program in 1998, which aimed to reduce the air pollution by using lead-acid battery based electric scooters to replace petroleum-powered scooters. Recently, a new incentive program by implementing a subsidy policy for purchasing electric scooters lug with Li-ion batteries together with smart infrastructures is proposed for combating the climate change. The present work has clearly reviewed the abovementioned programs and the main conclusions from the review are as follows:

1. A shift from petroleum-powered scooters to zero-emission scooters such as battery-powered electric scooters and fuel cell scooters has benefits of enhancing the energy efficiency and reducing the GHG emission.
2. The latest electric-scooter promotional program still faces the challenges of battery prices and safety. It is expected to fail as happened years ago if these obstacles cannot be overcome.
3. To capitalize on the full benefits of battery-powered electric scooters, it should consider lowering the carbon intensity of the national grid. The recently passed "Statute for Renewable Energy Development" in Taiwan, which increases the non-carbon electricity, is an example of policies that will help achieve that goal.
4. According to the well-to-wheels modeling results, the COG-based H_2 fuel cell scooters perform best in both GHG emission reduction and energy conservation among the three zero-emission scooters. Their benefits can be up to 88% and 52% in reducing GHG emission and saving total energy, respectively.

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